

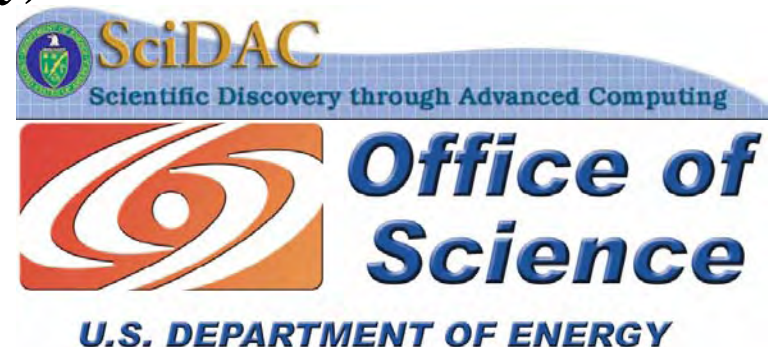
Modal Aerosol Treatment in CAM: Evaluation and Indirect Effect

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Current Aerosol Treatment in CAM3

sulfate

hydrophobic
black
carbon

sea salt 1

soil dust 1

ammonium

hydrophobic
organic
carbon

sea salt 2

soil dust 2

nitrate

hydrophilic
black
carbon

sea salt 3

soil dust 3

secondary
organic
carbon

hydrophilic
organic
carbon

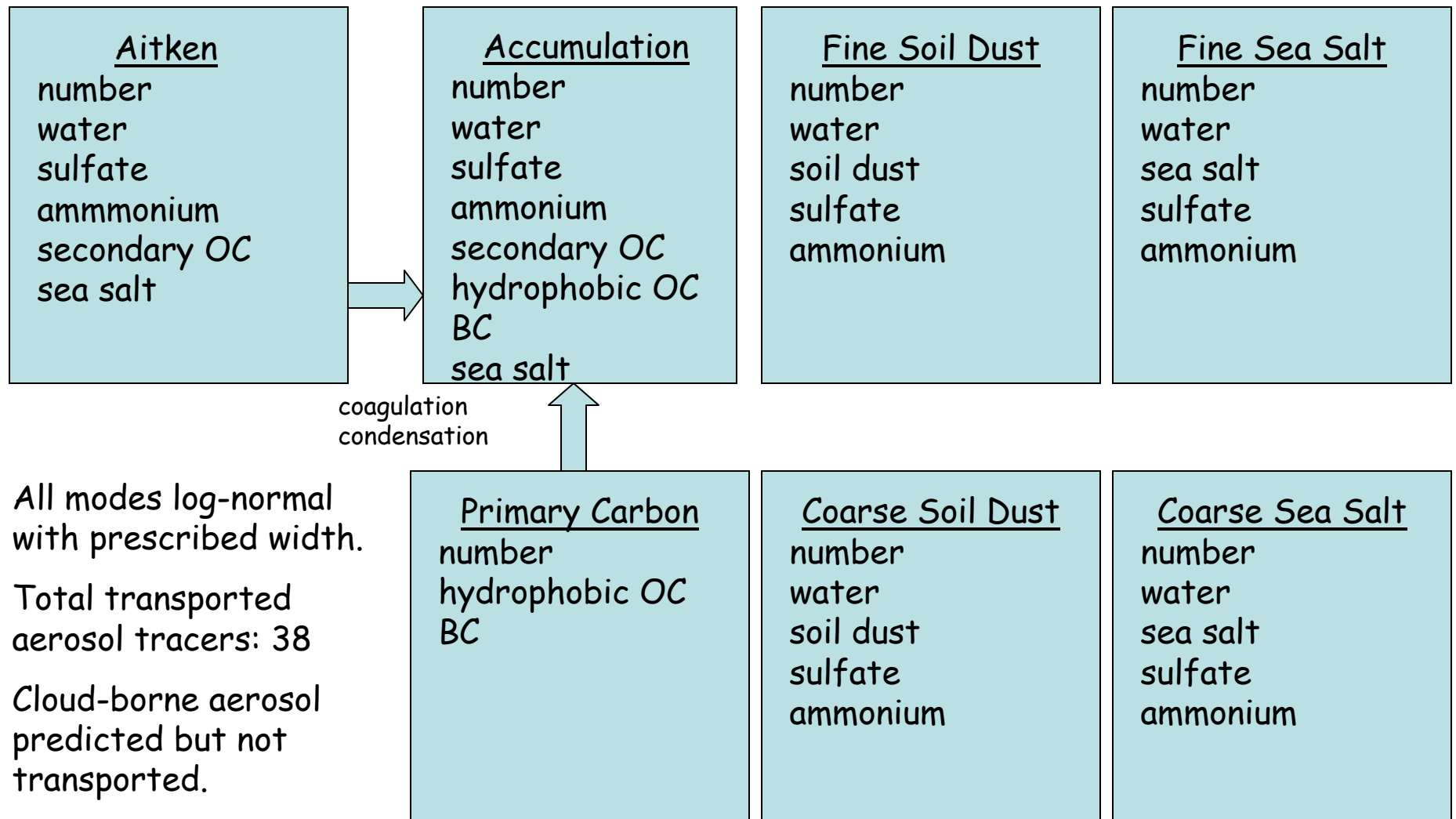
sea salt 4

soil dust 4

Current Weaknesses in CAM

- Aerosol species are externally mixed (individual particles are composed of only a single species).
- Their size distribution is prescribed (number is diagnosed from the predicted mass).
 - Processes that should only affect mass (condensation, chemistry) also affect number.
 - Processes that only affect number (nucleation, coagulation) are neglected.
- Hydrophobic carbon ages to hydrophilic with prescribed timescale

Benchmark Aerosol Treatment for CAM4



New Processes

- New particle formation
- Coagulation within, between modes
- Dynamic condensation of trace gas (H_2SO_4 , NH_3) on aerosols
- Water uptake to internally mixed particles
- Intermode transfer (renaming) due to condensation, coagulation, and cloud chemistry
- Aging of primary carbon to accumulation mode based on sulfate coating from condensation & coagulation
- Aerosol number emissions
- Aerosol activation

Revised Processes

- Wet scavenging (stratiform & convective cloud)
 - ✓ In-cloud rainout based on activated (cloud phase) aerosol;
 - ✓ Below-cloud impaction scavenging rates (mass & no.) using a look-up table (wet size, precipitation rate) .
- Size-dependent dry deposition (Zhang et al., 2001)
- Cloud sulfur chemistry
 - ✓ Sulfate mass produced distributed to modes based on number of activated aerosols in modes.
 - ✓ Include contribution from H_2SO_4 (g) uptakes
 - ✓ NH_3 dissolution on pH
- Optical properties of internally-mixed hydrated aerosol.
- Emissions of sea salt with diameters of 0.02-1.0 μm from Martensson et al. (2003)

CAM Simulations (CAM3.5.03)

- Modal aerosol (1.9x2.5), 3 years
 - benchmark present-day (PD) simulations
 - benchmark pre-industrial (PI) simulations
- Bulk aerosol (1.9x2.5), 3 years, present-day (PD) simulations

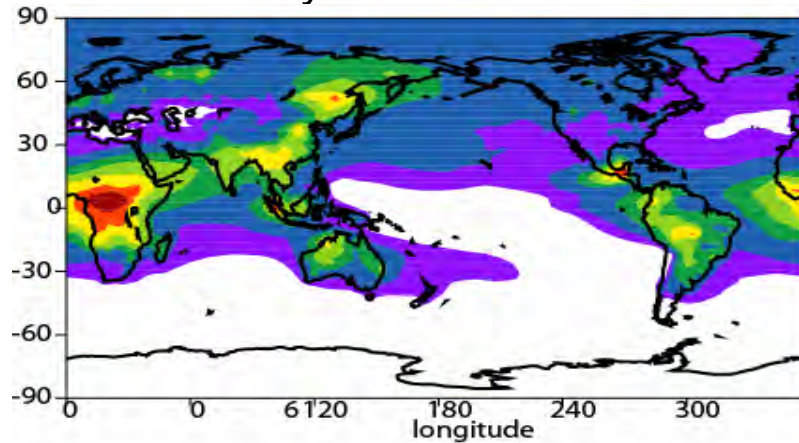
- **Same emissions (OC, BC, DMS, SO₂, SO₄) for PD**
- **Same emission schemes (dust and coarse sea salt)**
 - **ultrafine sea salt emission for Modal aerosol**
- **Same oxidant fields for PD and PI (Modal and Bulk)**

We can specify different MOZART chemistry mechanisms in the pre-processor to enable aerosol-chemistry coupling

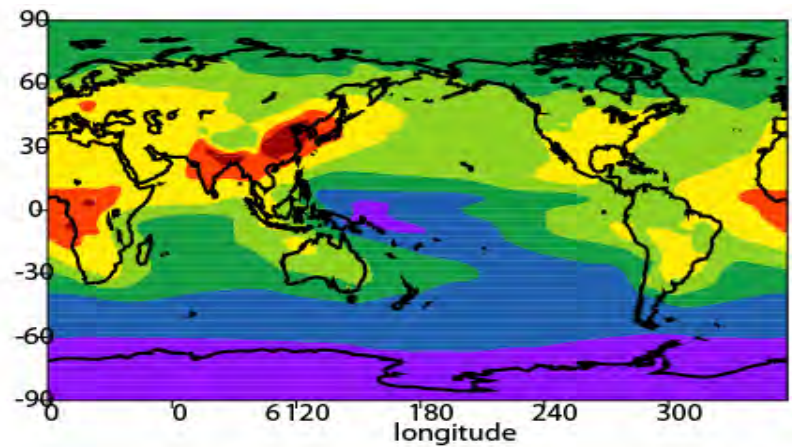
BC Column Burden

Modal

Primary carbon mode

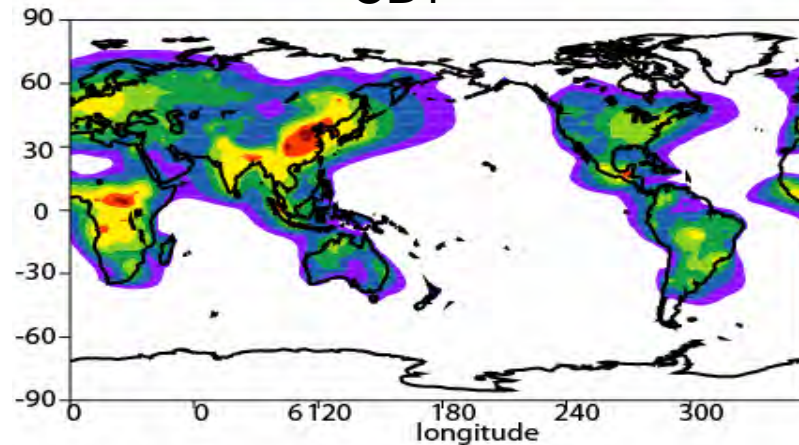


Accumulation mode

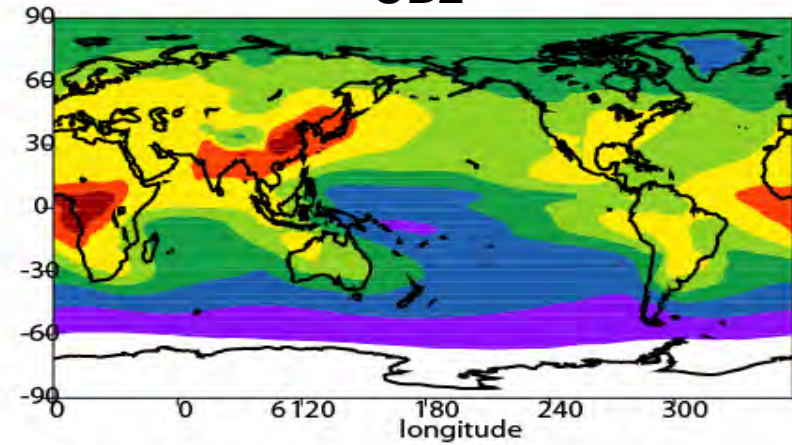


Bulk

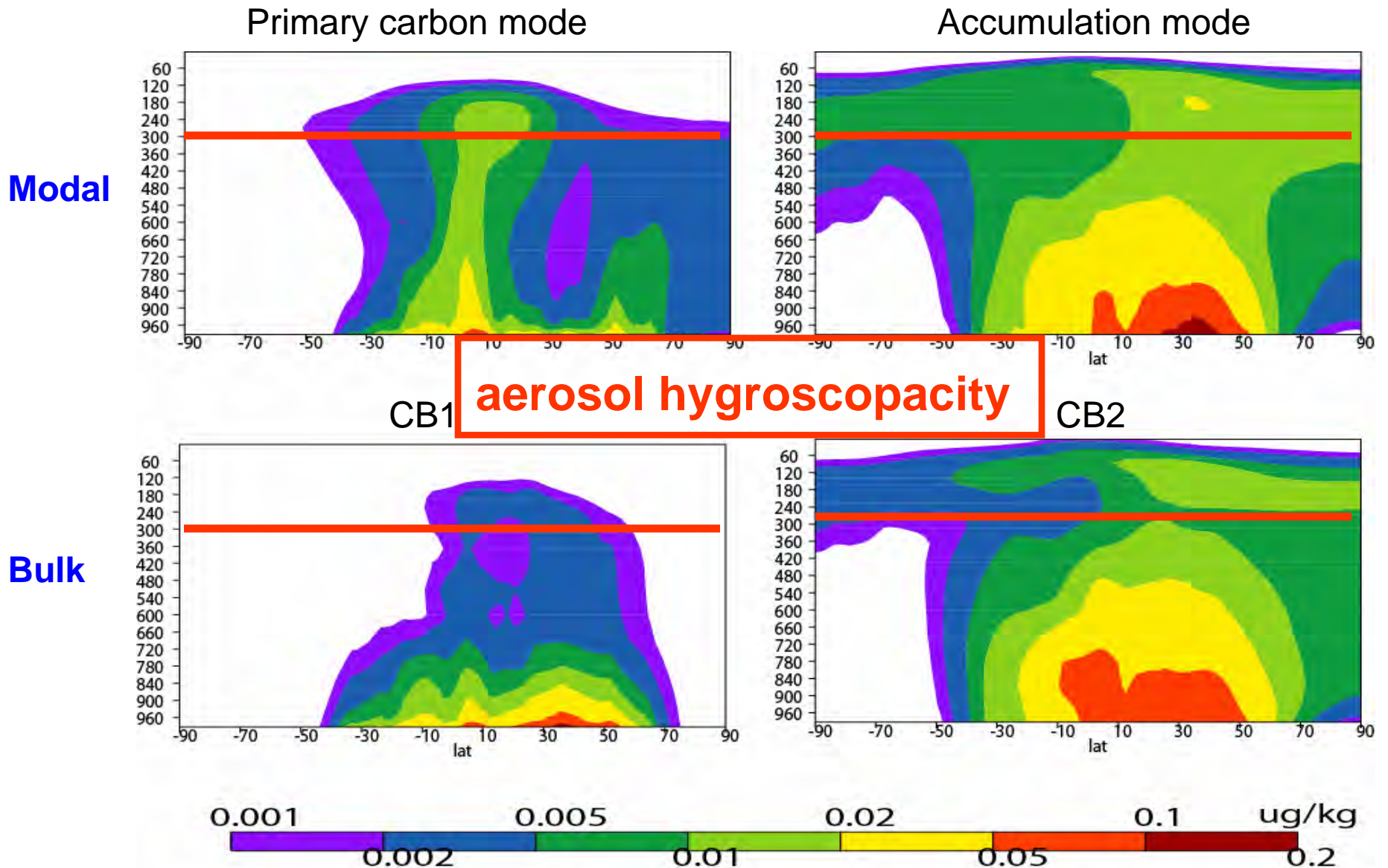
CB1



CB2



BC zonal mean



BC Budgets (Modal)

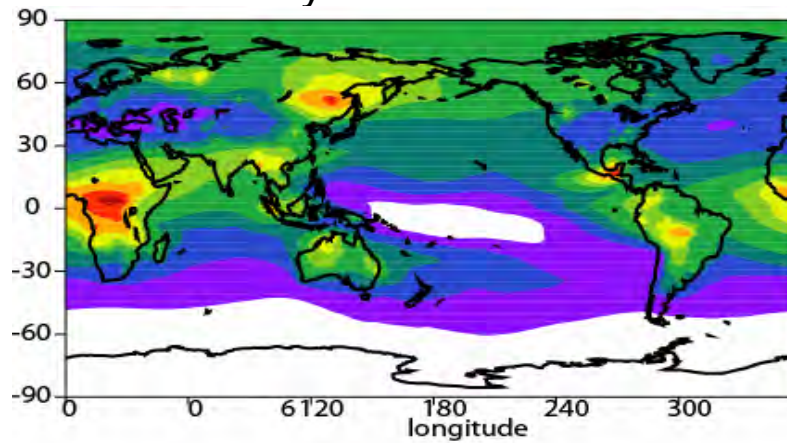
	Primary	Accum.	Total	Others
Emission (Tg/yr)	6.8		6.8	10-19
Dry deposition (Tg/yr)	0.7	1.6	2.3	
Wet deposition (Tg/yr)	0.0	4.5	4.5	
Total sink (Tg/yr)			6.8	
Burden (Tg)	0.024(0.02)	0.084(0.086)	0.11(0.11)	0.13-0.29
Lifetime (days)			5.8	3.9-8.4

Results from bulk model in blue

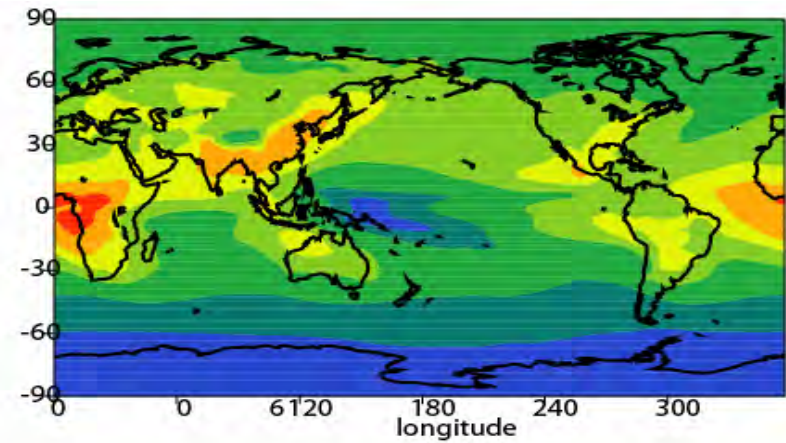
OC Column Burden

Modal

Primary carbon mode

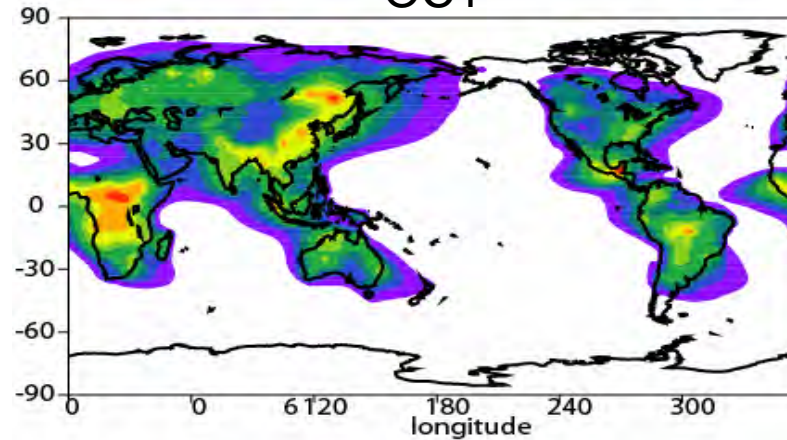


Accumulation mode

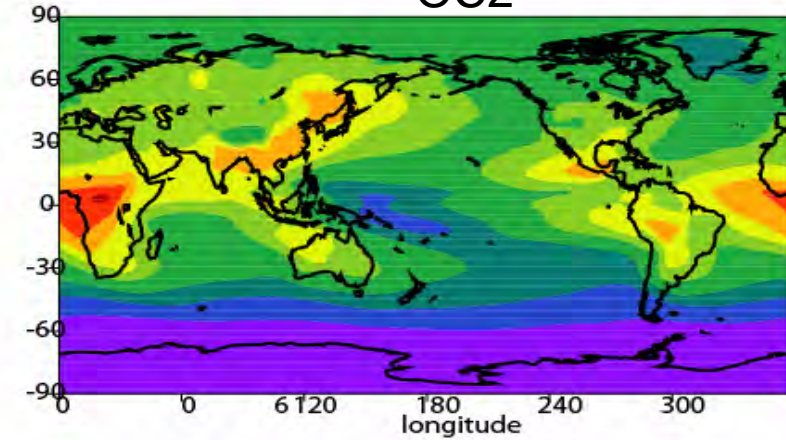


Bulk

OC1



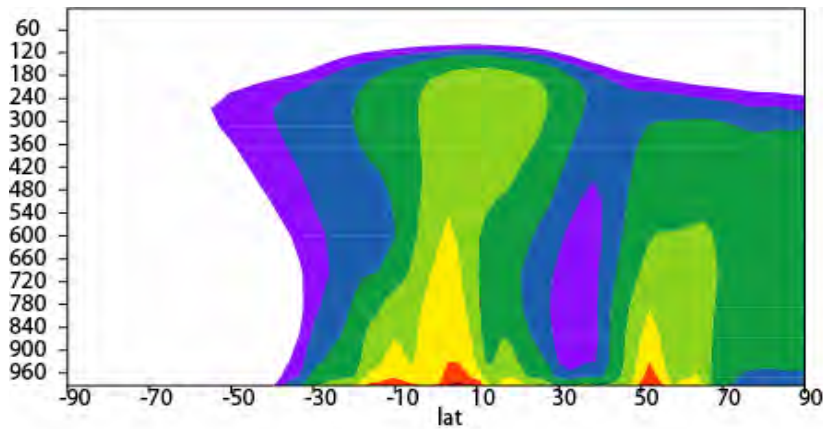
OC2



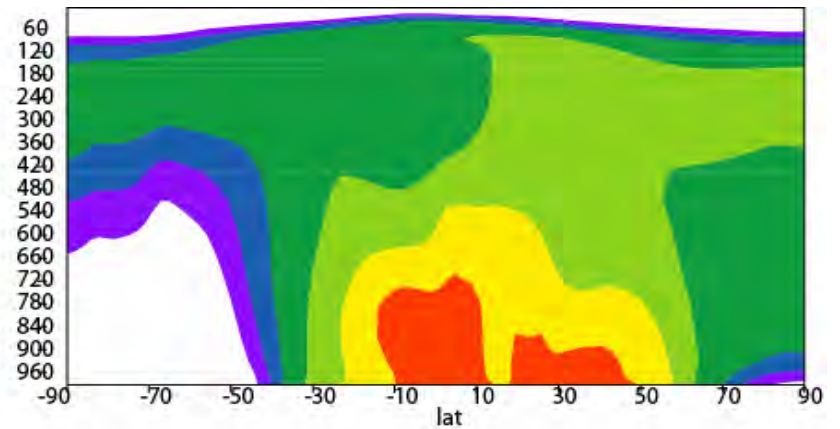
OC zonal mean

Modal

Primary carbon mode

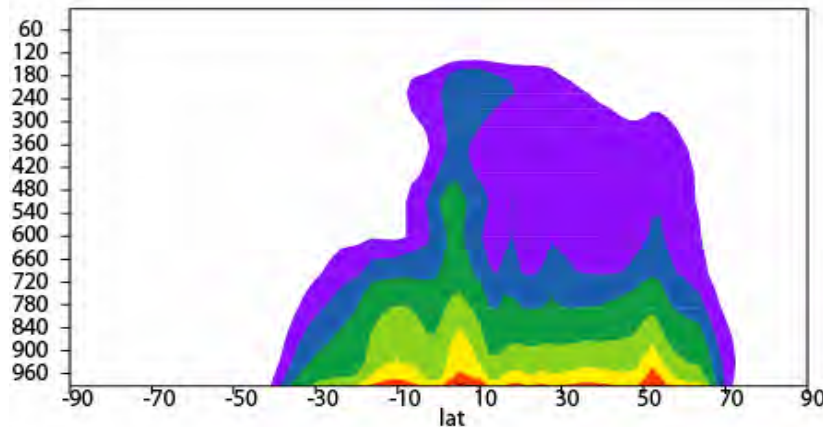


Accumulation mode

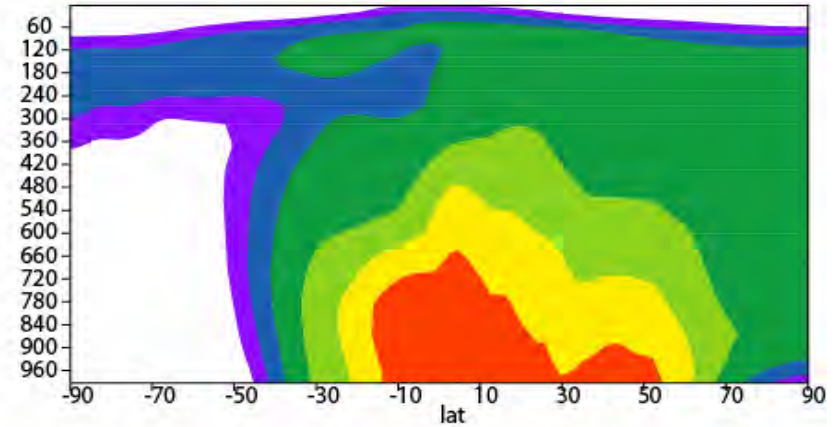


Bulk

OC1



OC2



OC Budgets (Modal)

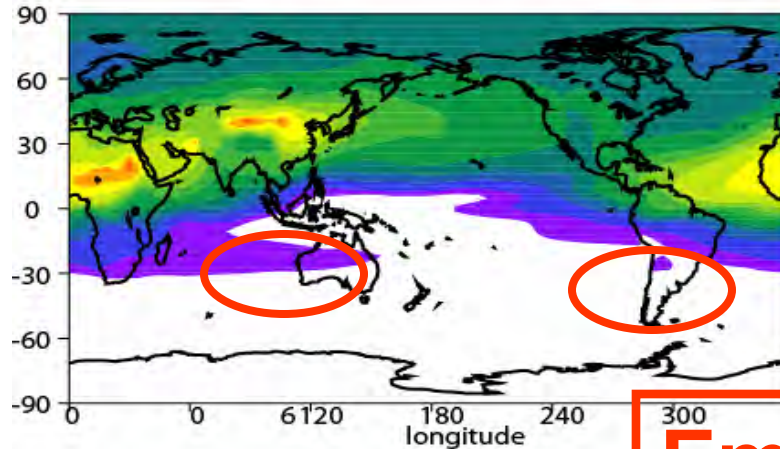
	Primary	Accum.	Total	Others
Emission (Tg/yr)	27.8		27.8	
Dry deposition (Tg/yr)	4.1	5.2	9.4	
Wet deposition (Tg/yr)	0.02	18.4	18.4	
Total sink (Tg/yr)			27.8	
Burden (Tg)	0.16(0.08)	0.38(0.38)	0.54(0.46)	0.95-1.8
Lifetime (days)			7.1	3.9-6.4

Results from bulk model in blue

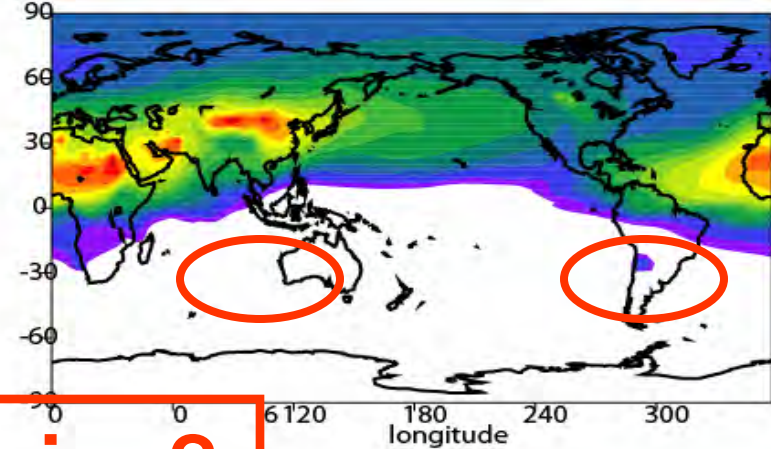
Dust column burden

Modal

Fine mode (0.1-2 μm)



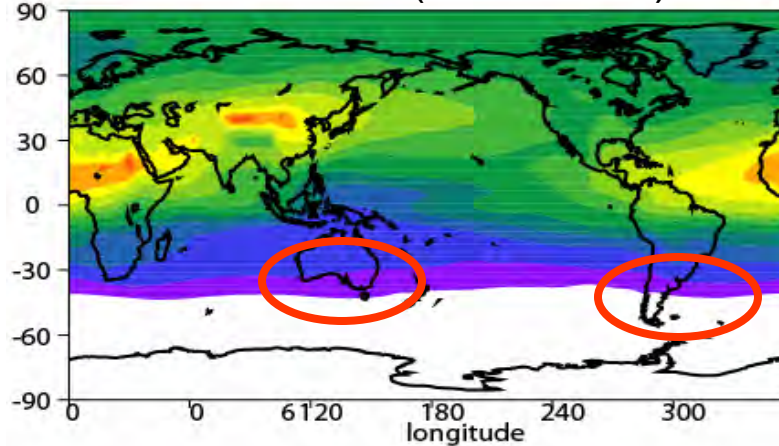
Coarse mode (2-10 μm)



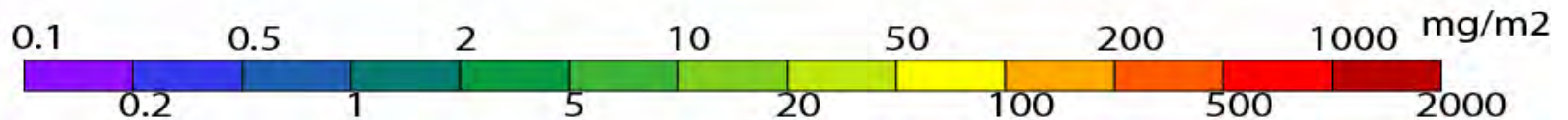
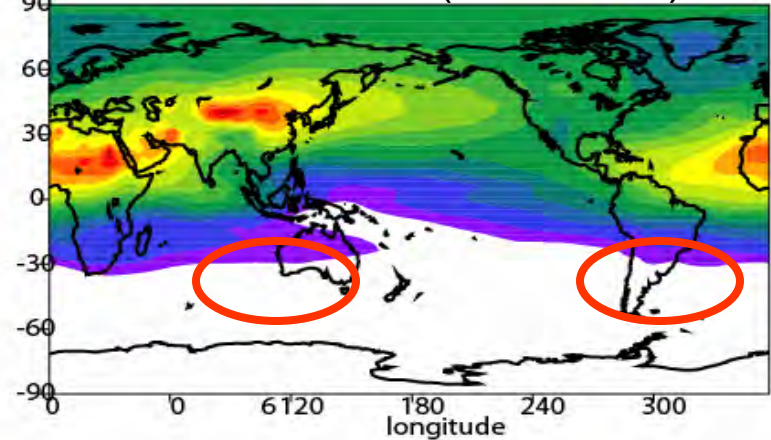
Emission?

Bulk

Fine mode (0.1-2.5 μm)



Coarse mode (2.5-10 μm)



Dust Budgets (Modal)

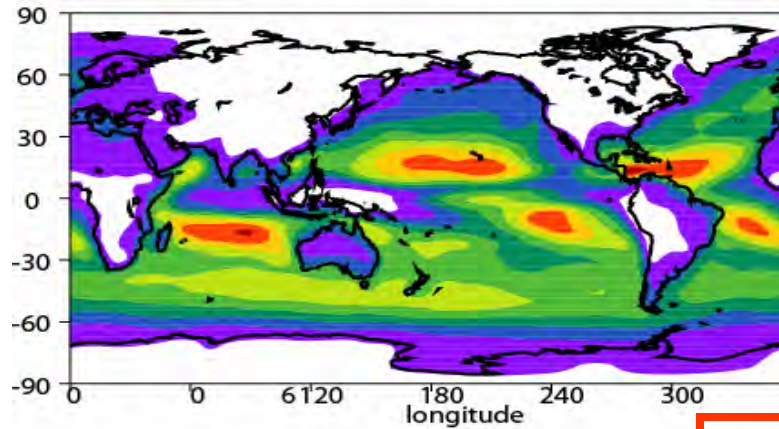
	Fine	Coarse	Total	Others
Emission (Tg/yr)	192	1282	1474(1567)	
Dry deposition (Tg/yr)	41	784	825	
Wet deposition (Tg/yr)	151	502	653	
Total sink (Tg/yr)			1477	
Burden (Tg)	3.0(5.4)	6.2(8.2)	9.2(13.7)	4-36
Lifetime (days)			2.3	1.9-7.1

Modal: 0.1-2 um (fine), 2-10 um (coarse);
Bulk: 0.1-2.5 um (fine), 2.5-10 um (coarse)

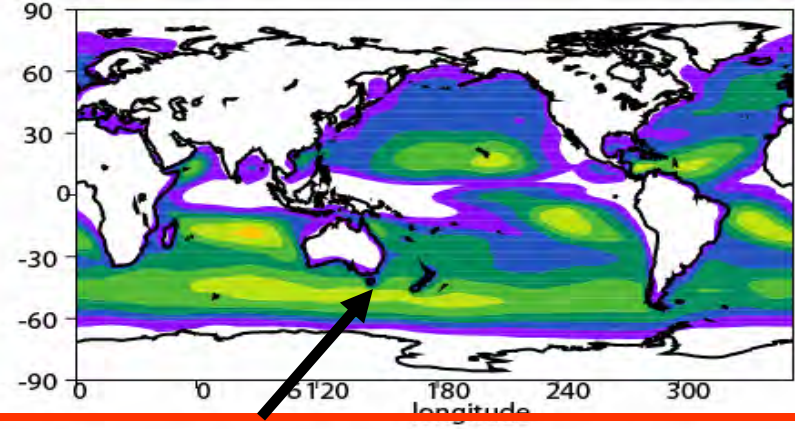
Sea salt column burden

Modal

Fine mode (0.02-1 μm)



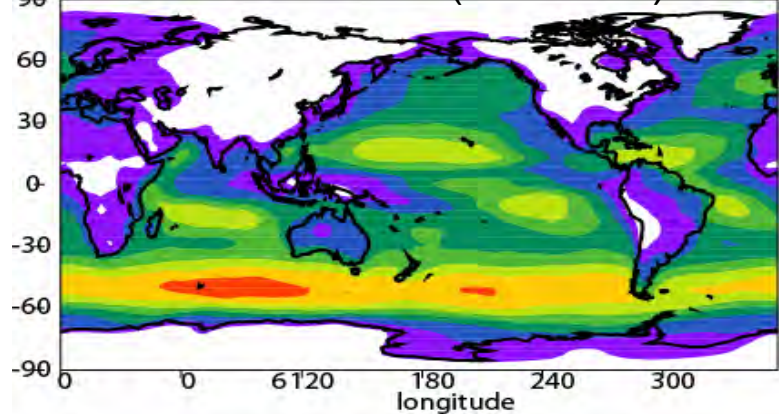
Coarse mode (1-10 μm)



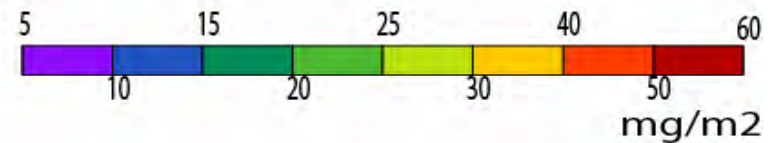
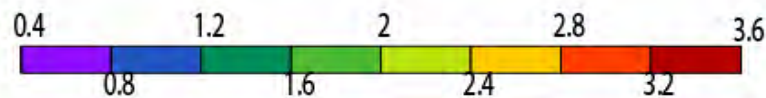
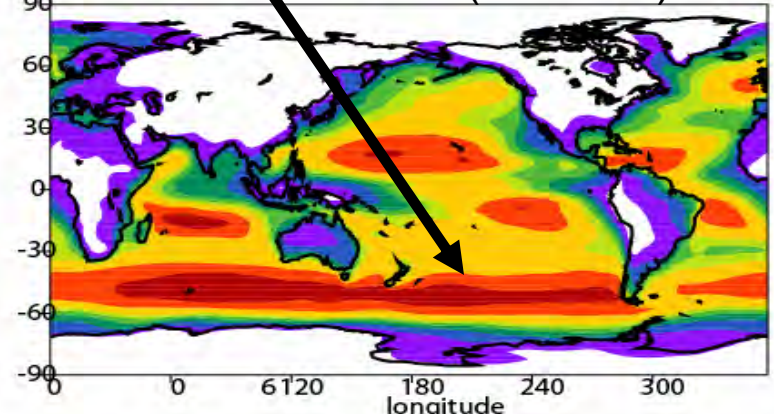
below-cld scavenging coefficient !

Bulk

Fine mode (0.2-1 μm)



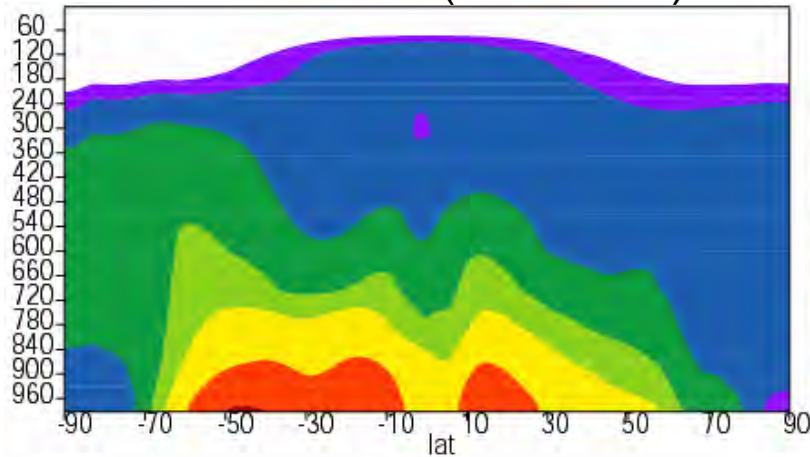
Coarse mode (1-20 μm)



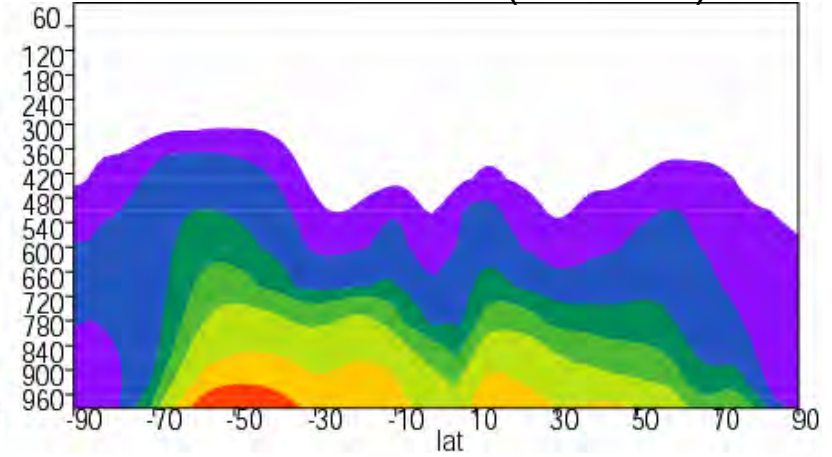
Sea salt zonal mean

Modal

Fine mode (0.02-1 μm)

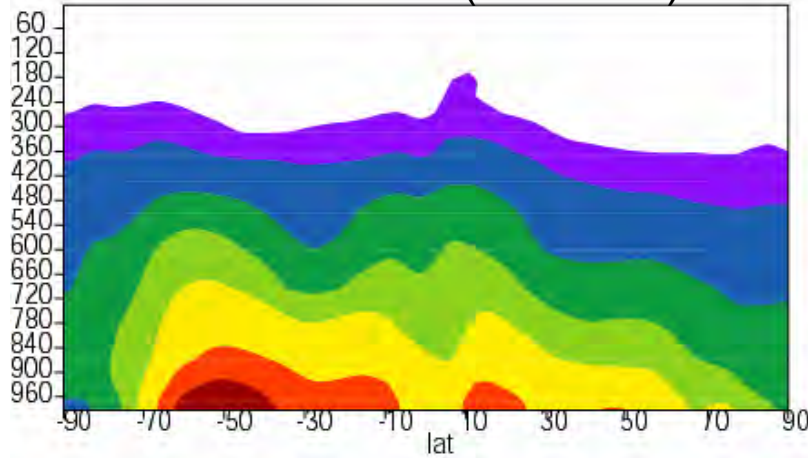


Coarse mode (1-10 μm)

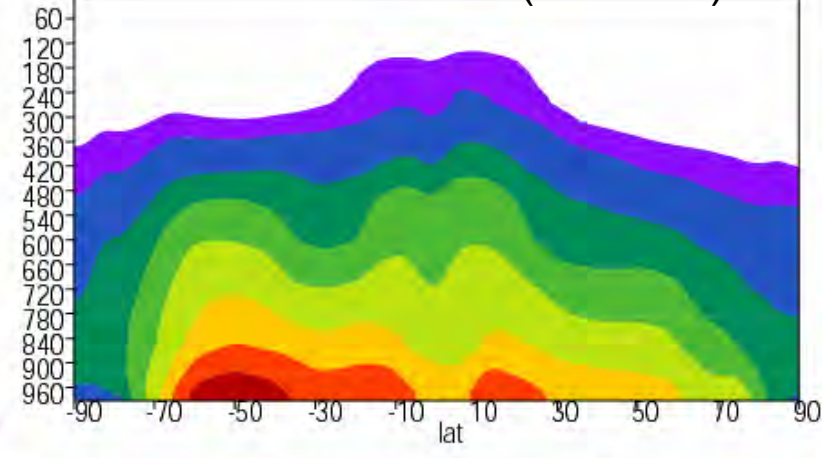


Bulk

Fine mode (0.2-1 μm)



Coarse mode (1-20 μm)

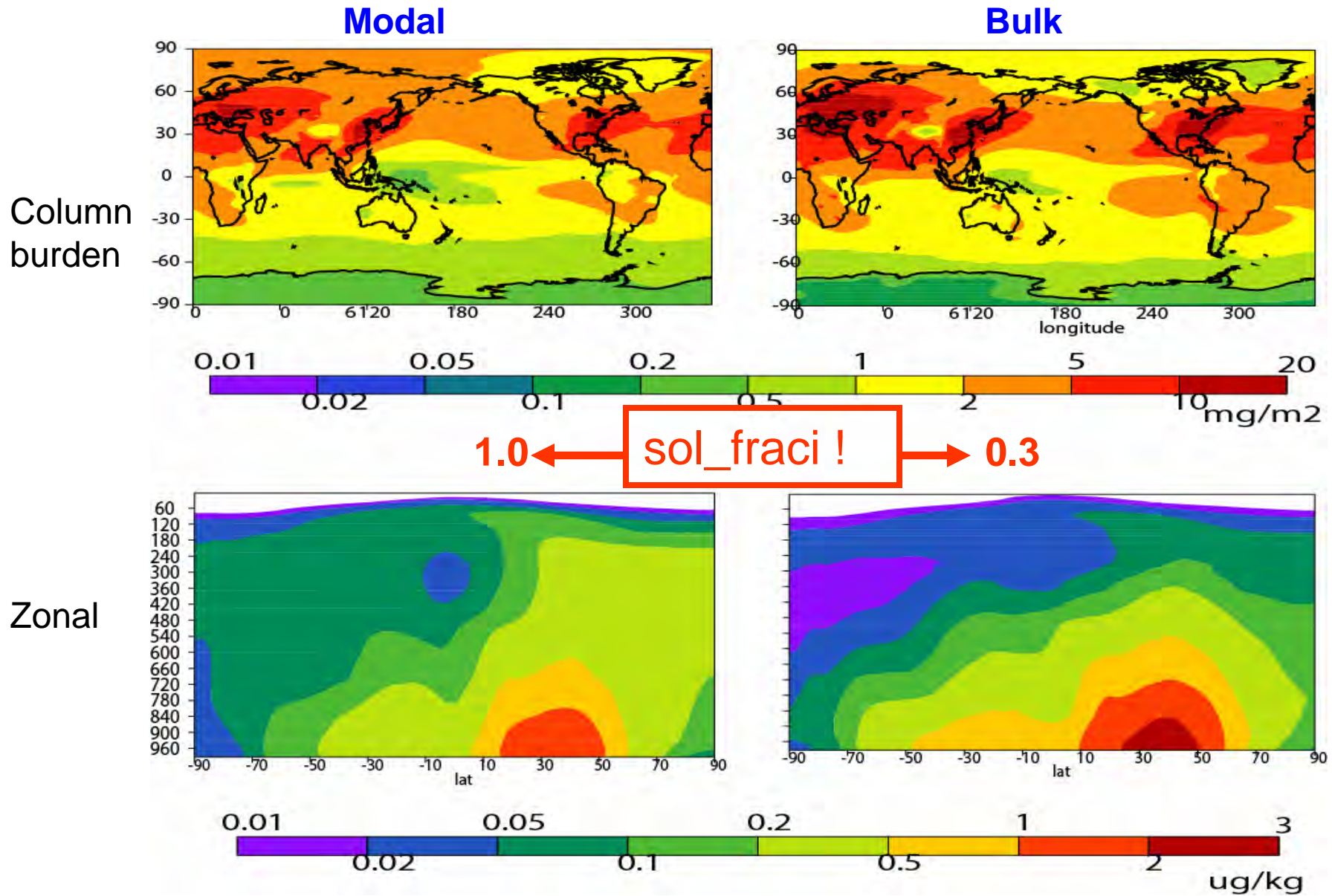


Sea Salt Budgets (Modal)

	<u>Fine</u>	<u>Coarse</u>	<u>Total</u>	<u>Others</u>
Emission (Tg/yr)	127	3709	3836 (3758)	
Dry deposition (Tg/yr)	23	1751	1774	
Wet deposition (Tg/yr)	105	1979	2084	
by below cloud		1046 (149)		
Total sink (Tg/yr)			3854	
Burden (Tg)	0.62 (0.63)	5.1 (11.0)	5.7 (11.6)	4.3-12
Lifetime (days)			0.54	0.19-0.99

Modal: 0.02-1 um (fine), 1-10 um (coarse);
Bulk: 0.2-1 um (fine), 1-10 um (coarse)

SO₄

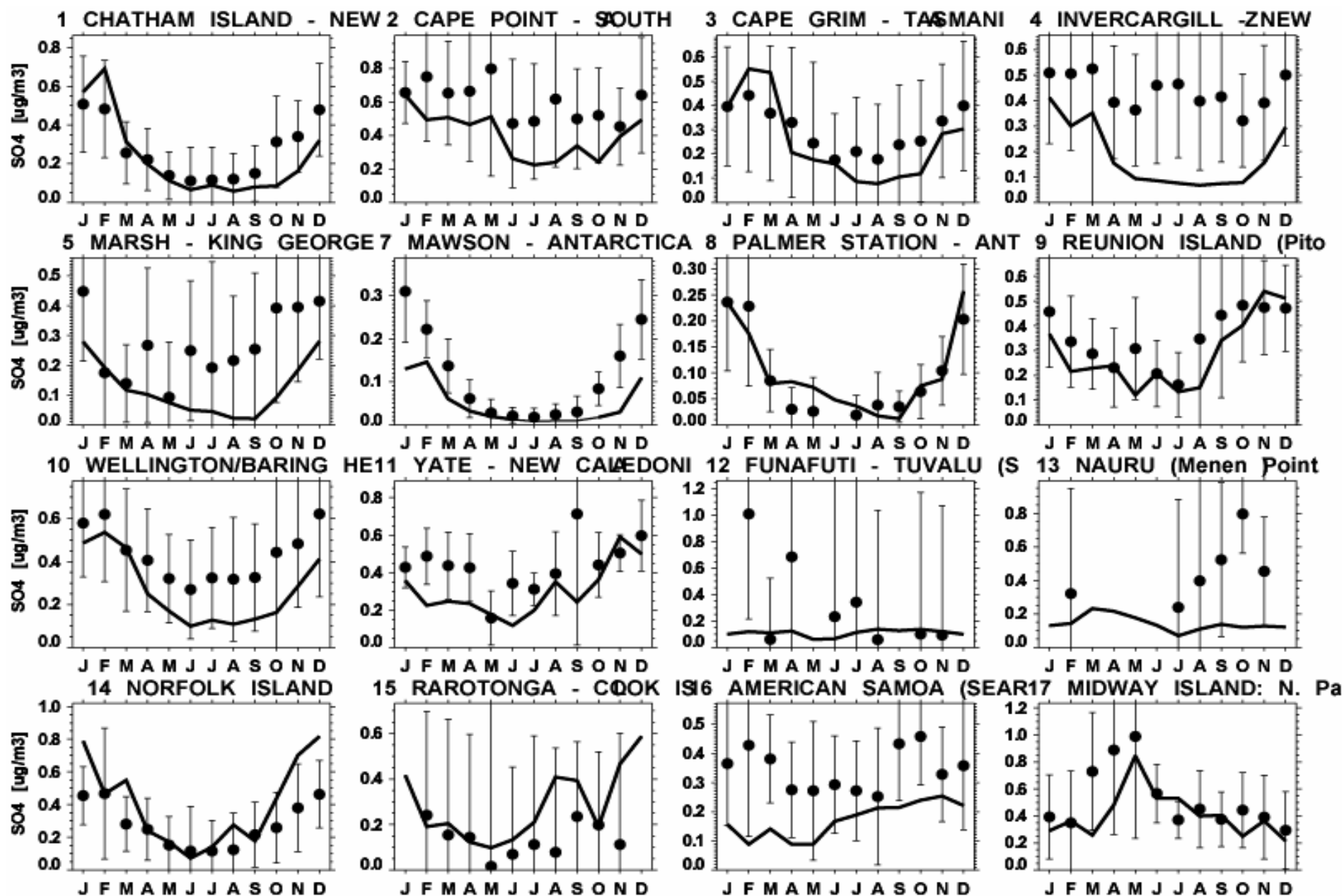


SO₄ Budgets (Modal)

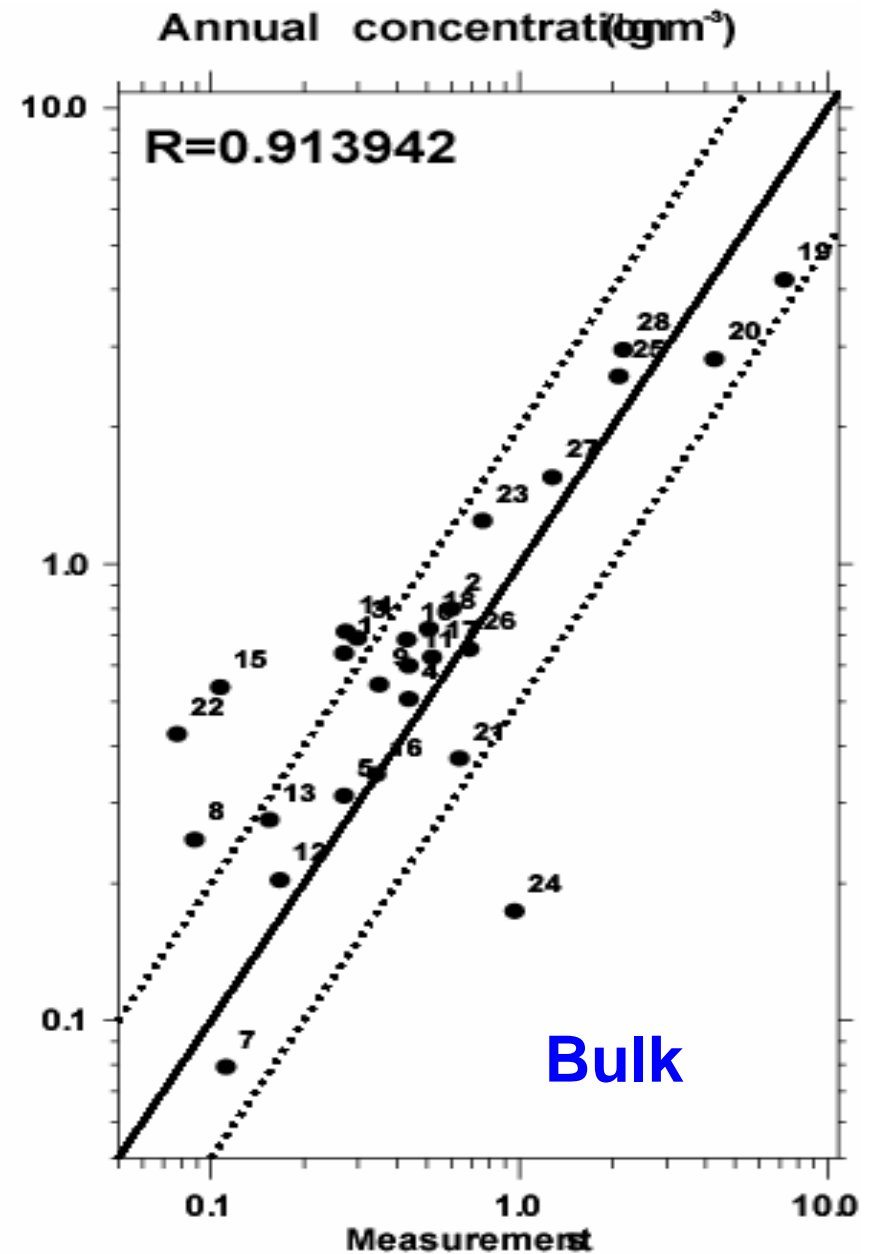
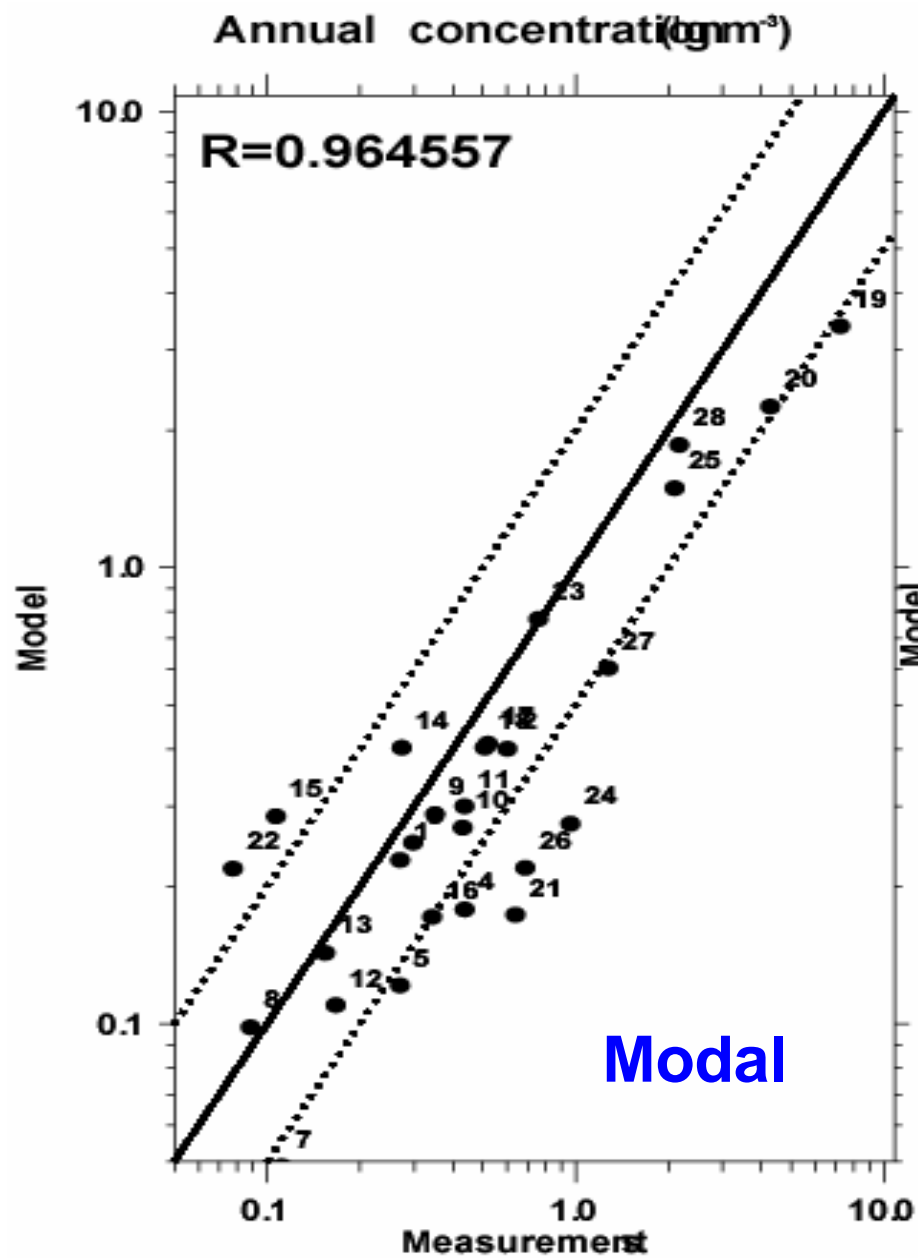
Burden (Tg S):	0.43(0.56)
Lifetime (days) :	3.3
Global dry deposition (Tg S/yr) :	8.8
Global wet deposition (Tg S/yr) :	38.7
Global SO ₄ sources (Tg S/yr) :	
by H ₂ SO ₄ condensation	9.5
by H ₂ O ₂	23.1
by O ₃	12.7
SO ₄ burden by reservoir (%):	
by SO ₄ nuclei mode	2.5%
by SO ₄ accumulation mode	92%
by Dust	3%
by Sea Salt	2.5%

Results from bulk model in blue

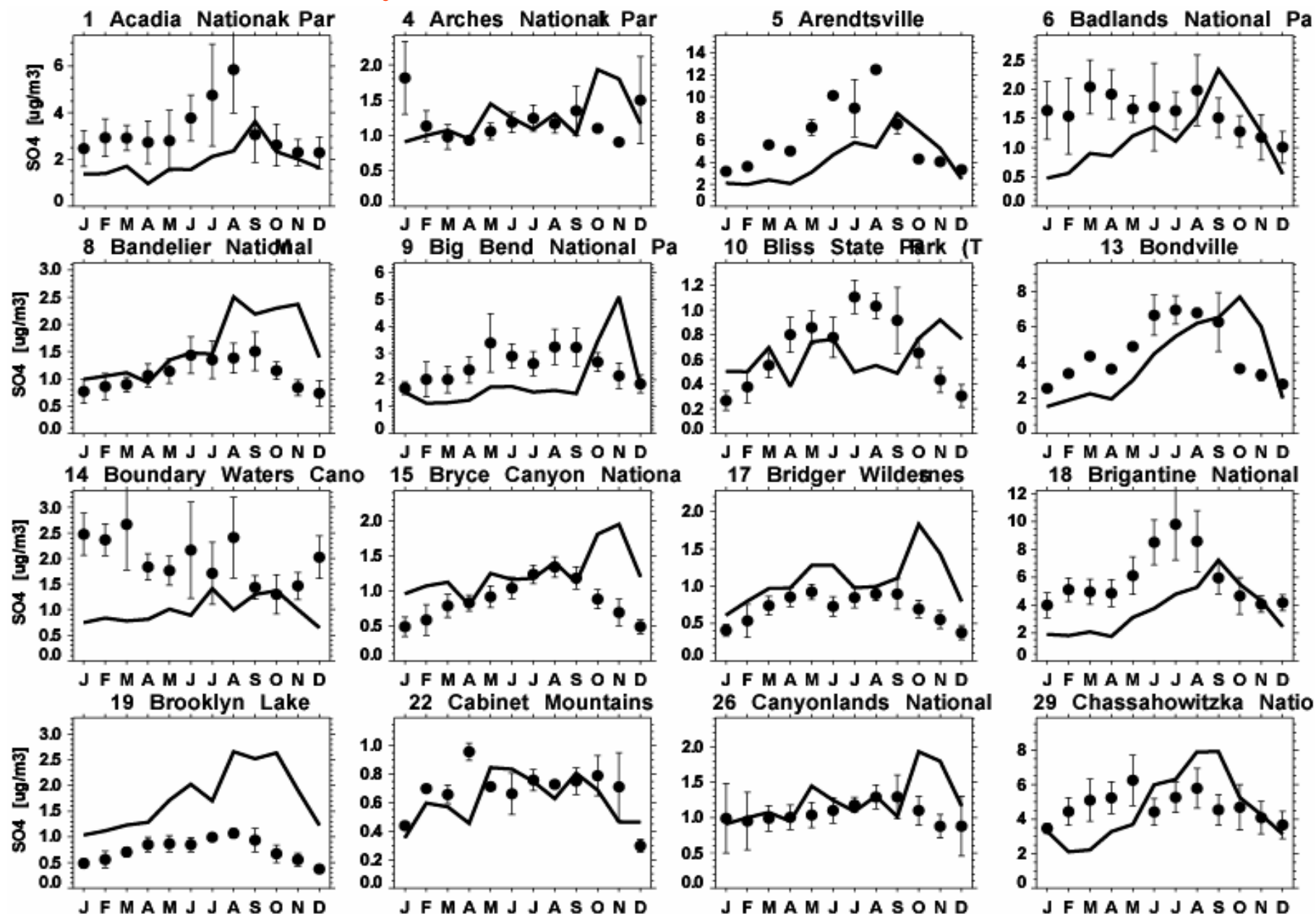
Modal - Compared with RSMAS SO4 Data



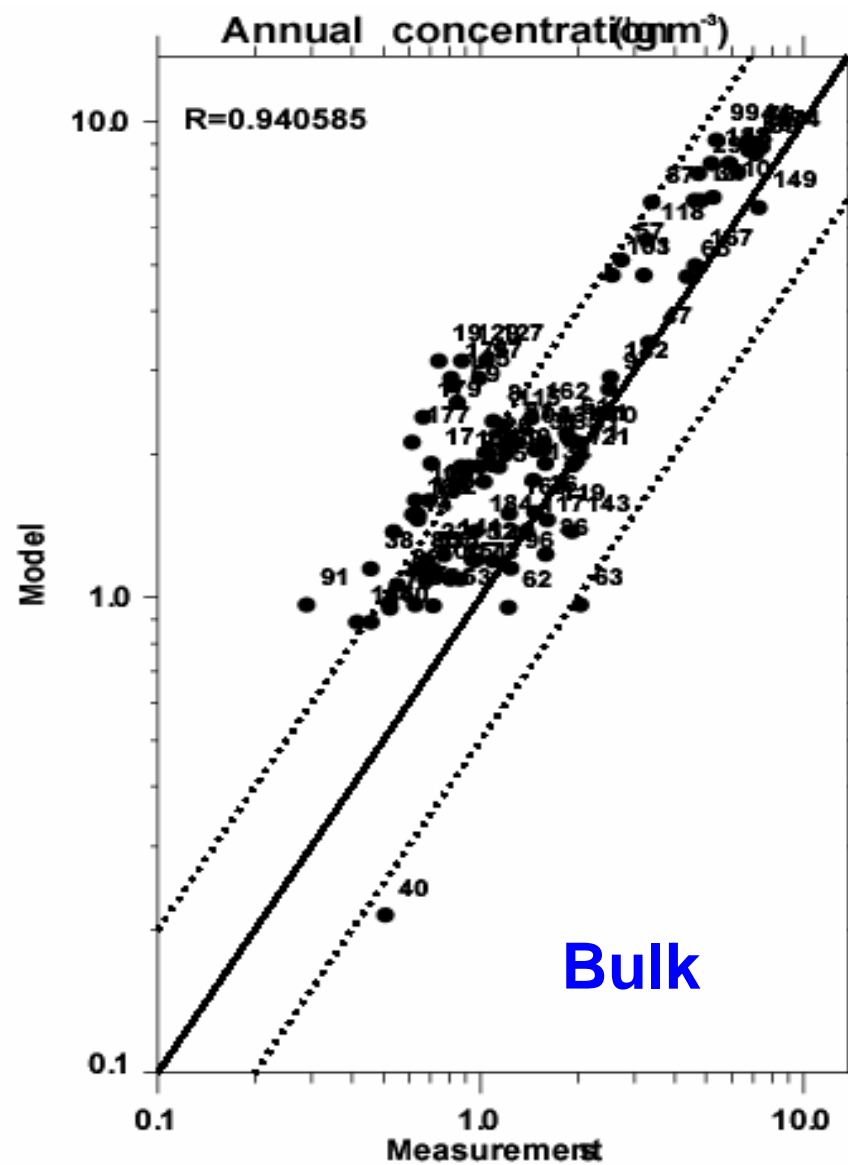
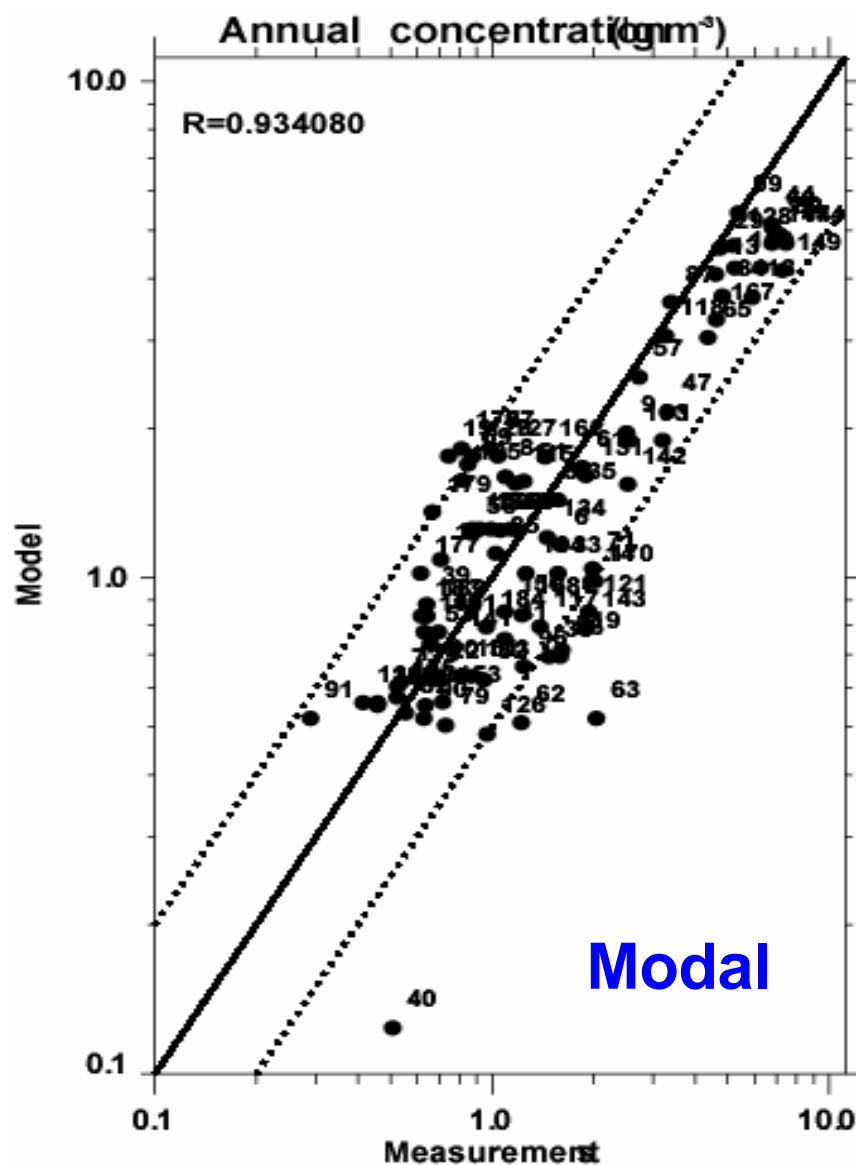
Compared with RSMAS SO4 Data



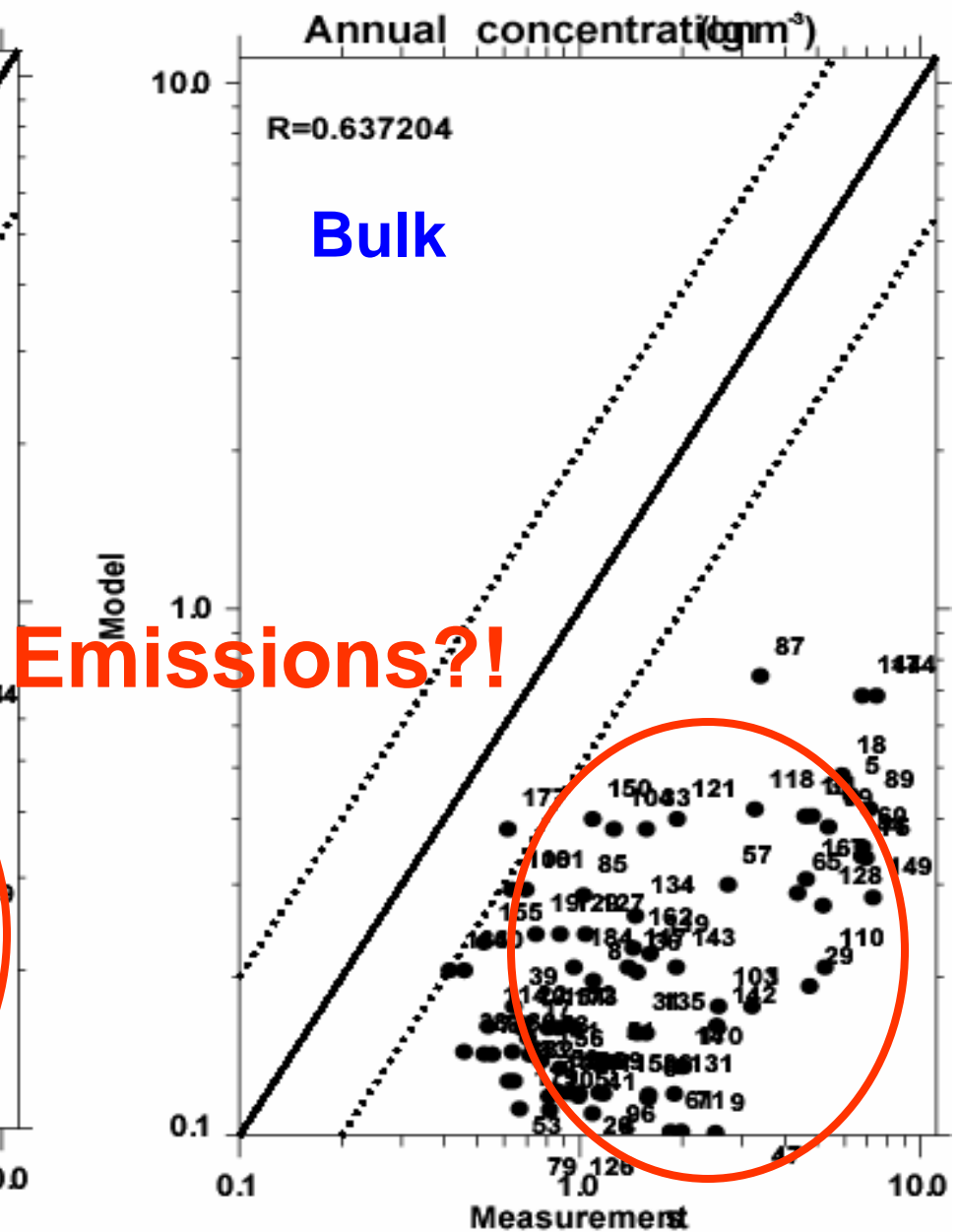
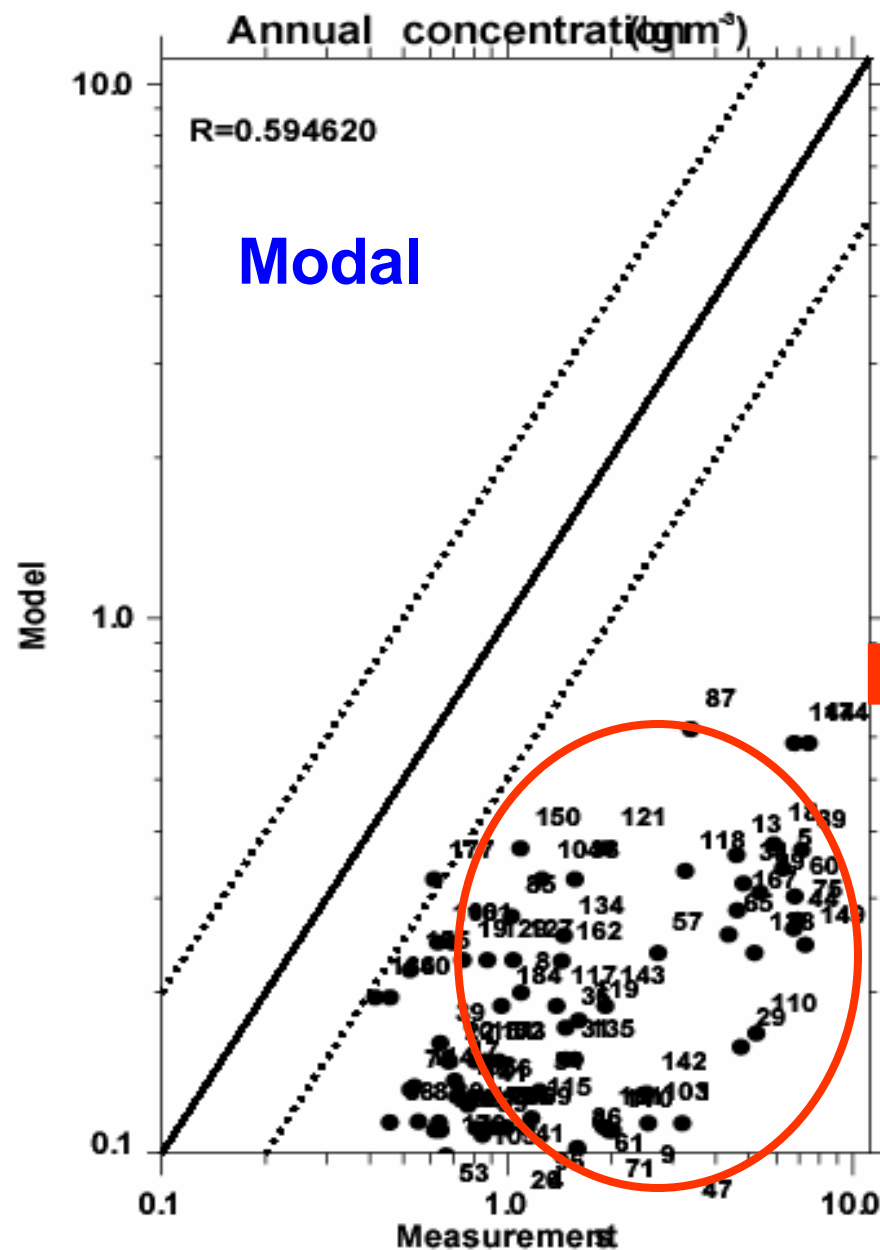
Modal - Compared with IMPROVE SO4 Data



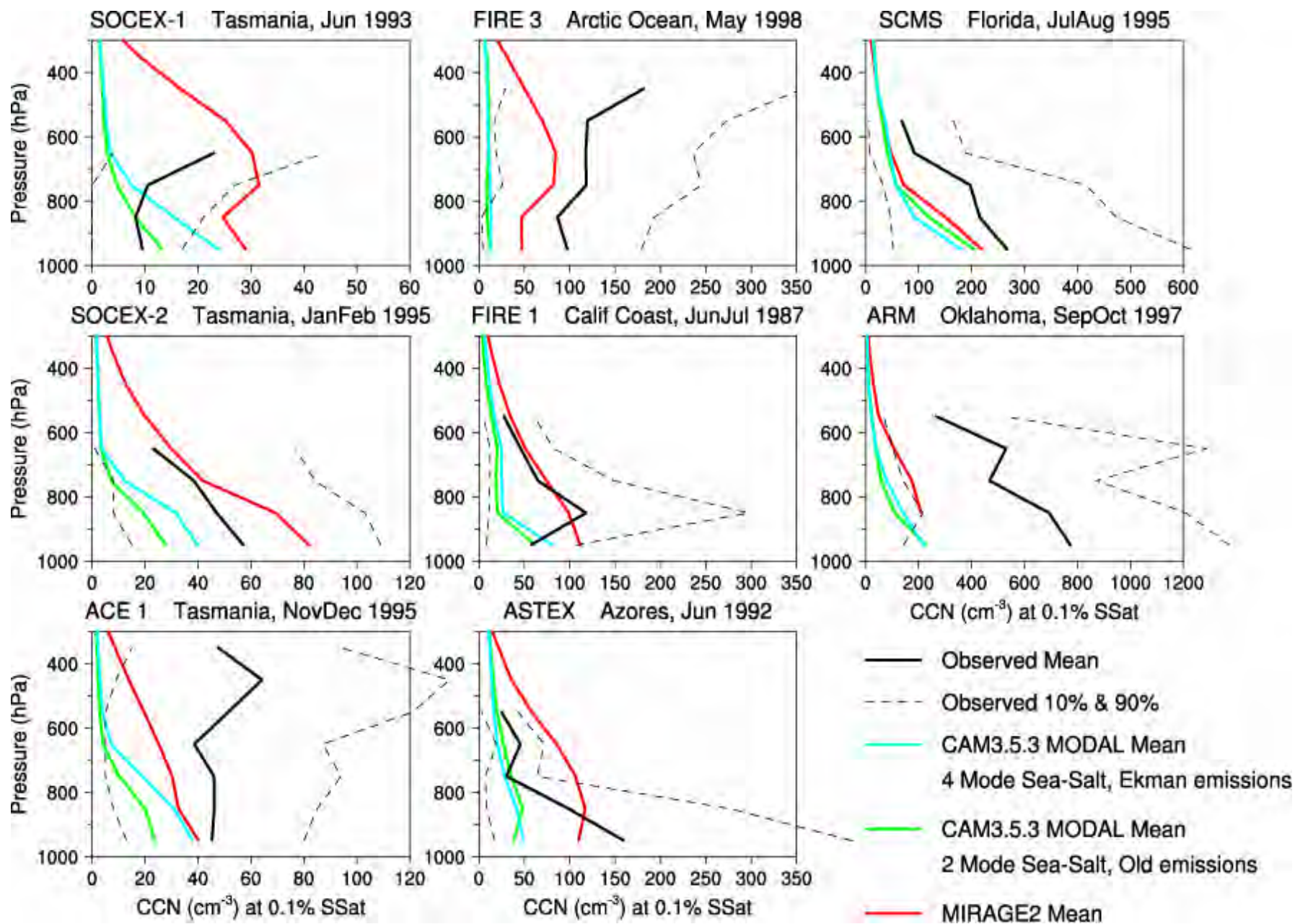
Compared with IMPROVE SO₄ Data



Compared with IMPROVE BC Data



CCN ($S=0.1\%$)

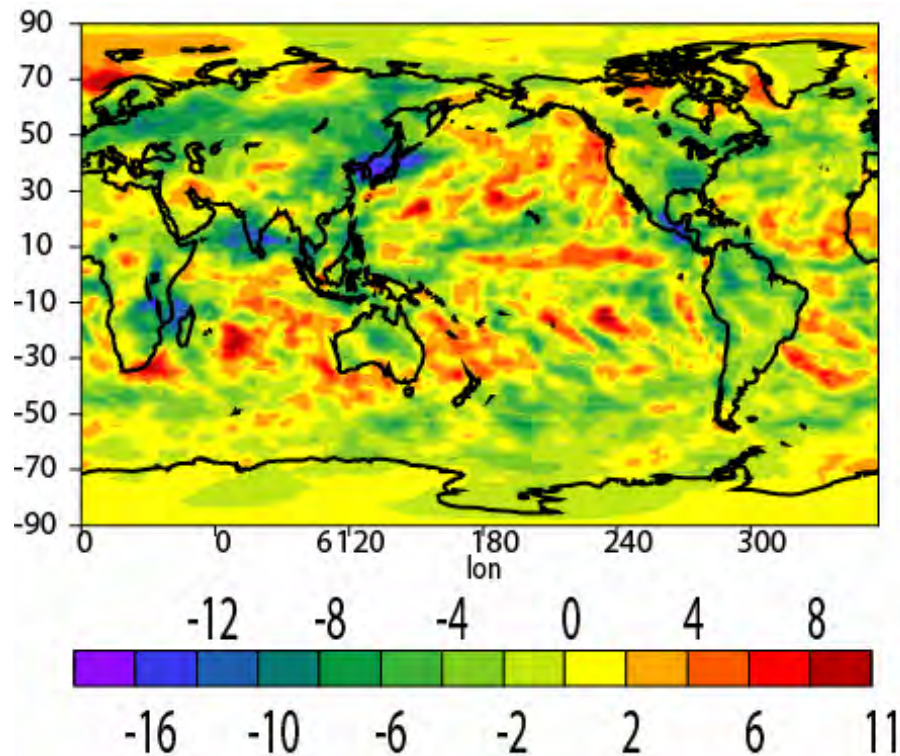


Global Annual Means (Present Day)

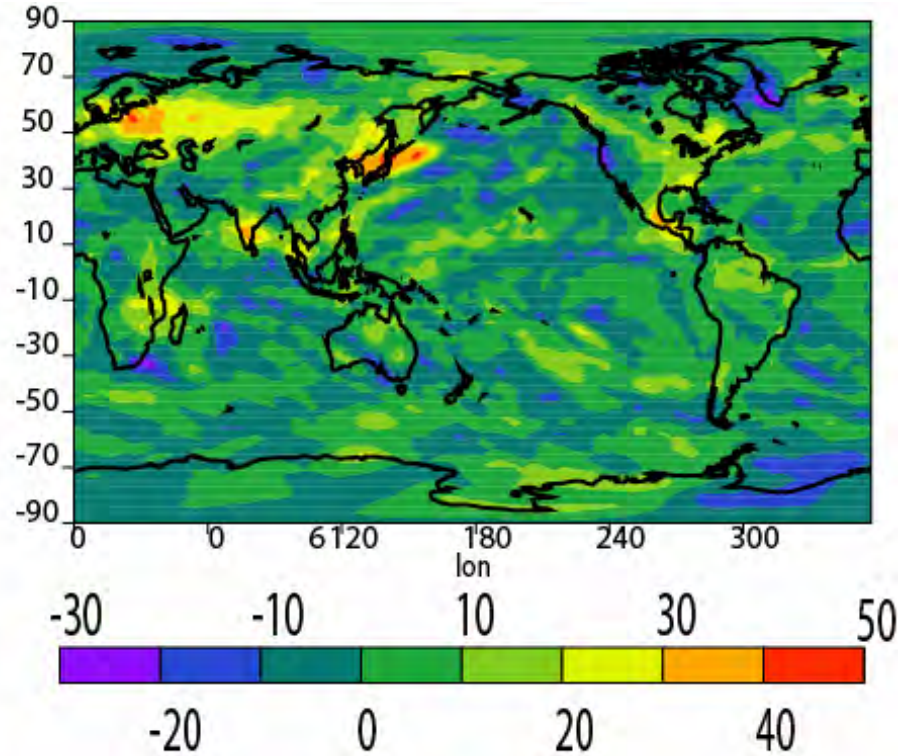
	Modal	Bulk	OBS
LWP, g m⁻²	104.5	129.9	
IWP, g m⁻²	15.5	15.9	
SWCF, W m⁻²	-58.3	-53.7	-54.2 (ERBE)
LWCF, W m⁻²	28.0	27.7	30.4 (ERBE)
FLNTC, W m⁻²	263.0	262.7	265.0 (ERBE)
CLDTOT, %	52.8	51.8	67.3 (ISCCP)
CLDLOW, %	35.5	34.4	21.8/33.6 (ISCCP/SAGE)

Aerosol Indirect Effect

Present – Past Shortwave Cloud Forcing (W/m²)

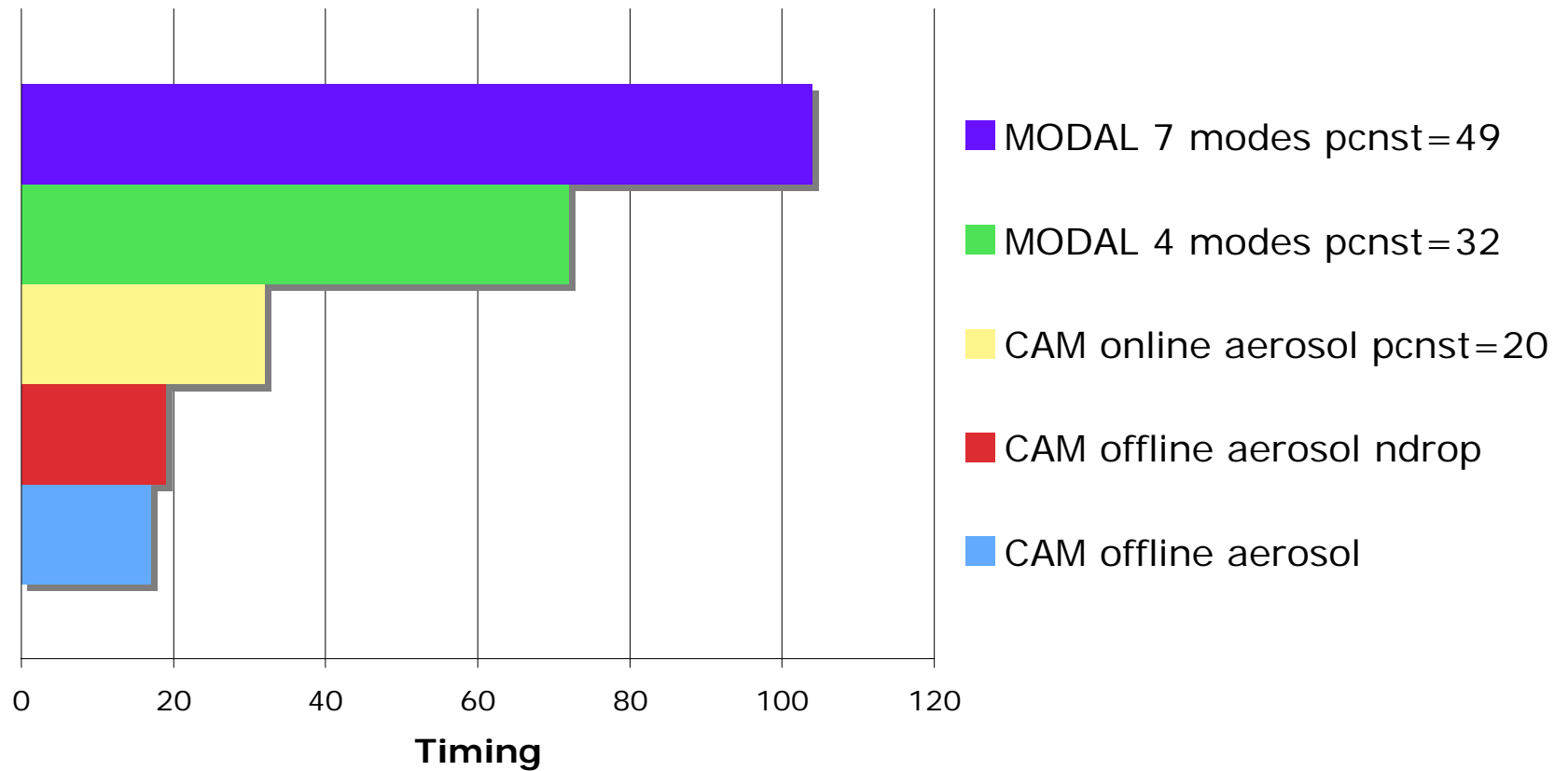


Present – Past Liquid Water Path (g/m²)



Global Mean = -1.1 W/m²

Timing



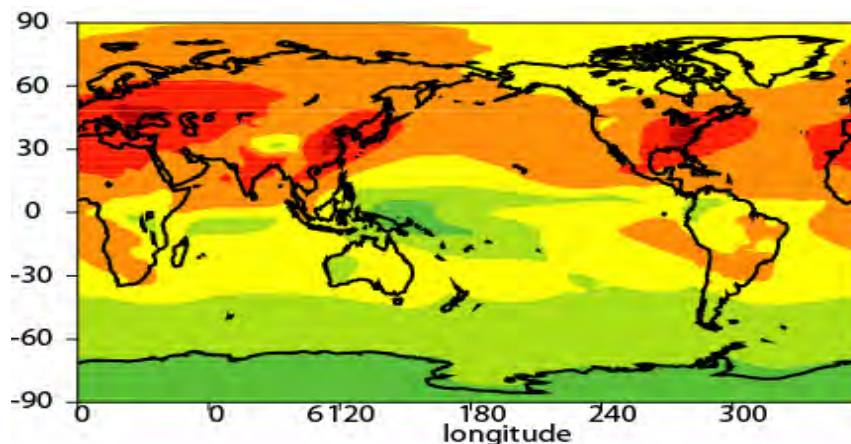
Remaining issues

- Simulation with Morrison microphysics and Modal aerosol reduces the simulated SWCF to -47 W/m^2 , which is $7\text{-}10 \text{ W/m}^2$ too small.
- Simulations with Morrison microphysics and Mozart aerosol using the UW PBL scheme produce excessively *large* SWCF.
- Simulations coupling Modal aerosols with Morrison microphysics and the UW PBL scheme should be performed.
- The simpler version of Modal aerosol should be evaluated.
- Improvements in primary carbon emissions are needed.
- A secondary organic aerosol mechanism for modal aerosol is under development.
- Evaluate simulated aerosol optical depth.

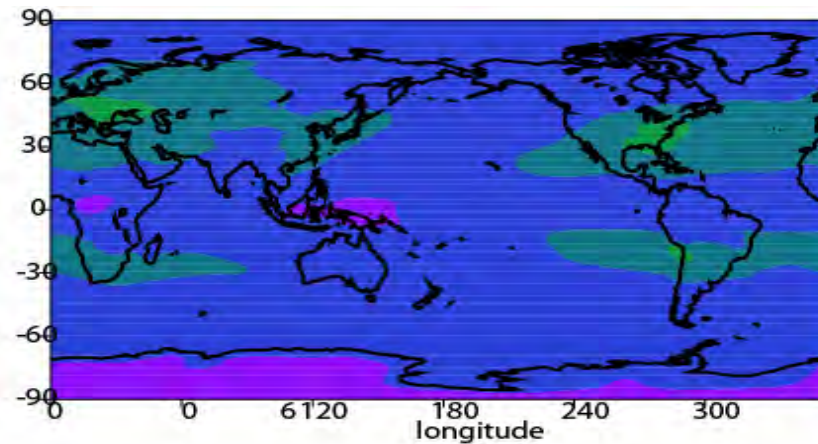
THANKS!

SO₄ column burden (Modal)

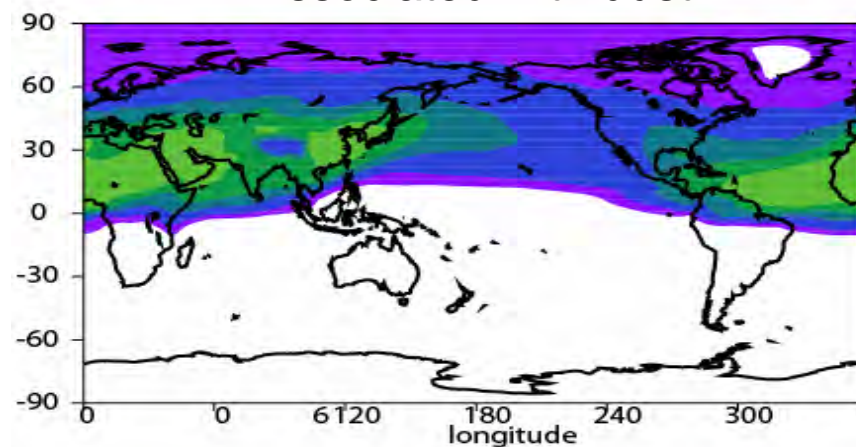
Accumulation mode



Aitken mode



Associated with dust



Associated with sea salt (>0.3 μm)

